BOOM-BOAT DRIVE AND STEERING SYSTEM

This case describes how a mechanical engineer went through the engineering design process from the recognition of a problem to the production of a finished product. It encompasses many important aspects of engineering design, including, to varying degrees, creative thought, analysis, synthesis, decision-making, optimization, patents, and professional ethics.

Written by R. E. McKechnie, University of British Columbia.
Published with support from the sponsors of the ASEE-Stanford Engineering Case Program:

E. I. du Pont de Nemours and Company
The General Electric Foundation
IBM
Olin Corporation Charitable Trust
Union Carbide Corporation

BOOM-BOAT DRIVE AND STEERING SYSTEM

A boom-boat is typically a small (10 to 15 feet long), highly manoeuverable, steel-hulled boat. Boom boats are used by logging companies to sort floating logs and assemble them into booms for towing, and by pulp mills and sawmills to help feed logs from storage ponds into the mill. Although they may occasionally pull logs, boom-boats generally function by pushing one or more logs with their blunt bows or by grappling onto the logs and towing them alongside.

In contrast to tugboats, which have powerful engines and deep displacements to enable them to pull heavy loads (log booms, barges, etc.) from one place to another in often rough seas, boom-boats are characterized by high manoeuverability and shallow displacements. These characteristics enable boom-boats to manoeuver easily in their normal environment -- a relatively confined area of shallow, sheltered water, usually full of logs and other obstructions.

The early boom-boat was essentially a miniature tugboat. Although it was small and had a shallow displacement, it was powered by a conventional engine-gearbox-propeller combination and steered with a rudder located aft of the propeller. This method of propulsion and steering severely limited the manoeuverability of the boom-boat. A minimum radius of turn was typically about 50 feet, as shown in Figure 1 a. Because the boat often had to turn around with a radius less than this, much time would be lost as the operator turned the boat in a series of forward and reverse motions as shown in Figure 1 b.

QUESTION 1: How could the boom-boat design be altered to improve manoeuverability? You should be able to list three or four conceptual ideas for improvement.

Shortly after the second world war, much of the boom-boat industry adopted an idea which originated in Germany. Thrust from the propeller was directed not past a rudder, but into a cylindrical shroud which could be pivoted roughly 60° either side of center to change the direction of thrust and thus steer the boat. Because there was a more positive control over thrust, this innovation resulted in a turning radius of approximately 10 feet, and manoeuverability was considerably improved.

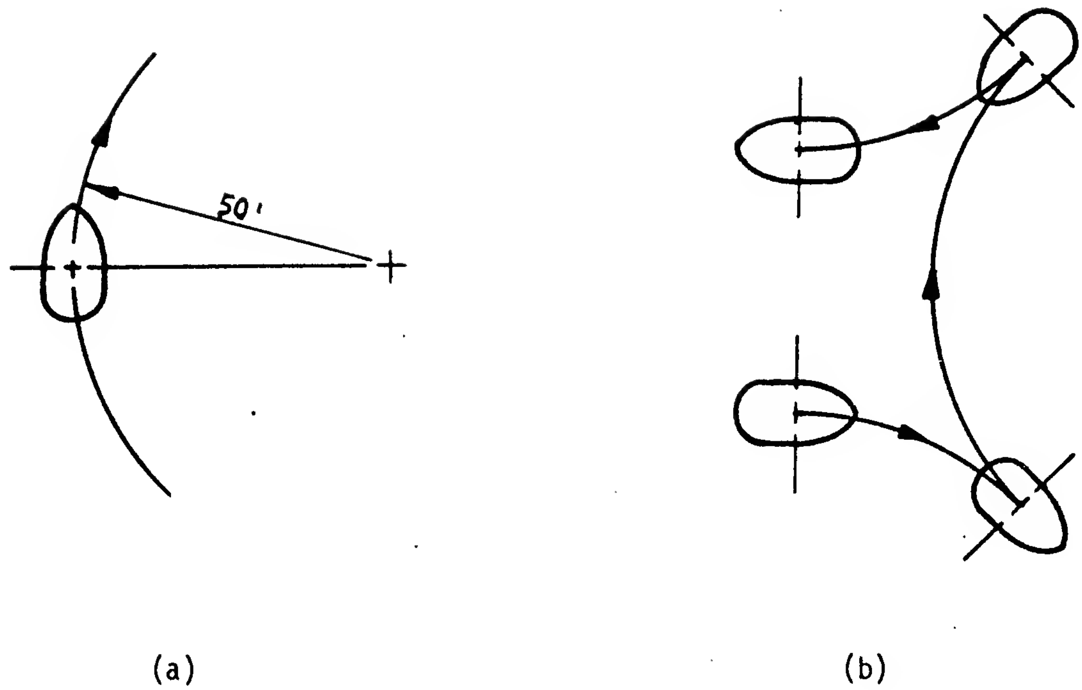

Fig. 1: Turning Radii

In the late 1950's, a few companies experimented with what was hoped would be a significantly improved boom-boat design. This design featured an open well through the boat's hull, approximately one-third of the way from the bow to the stern. A conventional outboard motor was mounted in the well in such a way that the operator could turn it a full 360° to steer the boat.

With this improvement, the boom-boat was indeed much more manoeuverable. By turning the outboard motor 90° from its normal aft-thrusting direction, the boom-boat could be made to pivot about its vertical axis, effectively decreasing the turning radius to zero. By turning the motor 180°, the operator could apply full reverse thrust without shifting gears or changing engine speed. Unfortunately, the outboard design had two major limitations.

QUESTION 2: Can you name the two major limitations to the outboard motor design?

The first limitation of the outboard motor design was that when pushing a heavy load such as a log, the boom-boat required low speed, high torque power to prevent the propeller from cavitating in the water. Conventional outboard motors delivered their maximum power only at high speeds, and cavitation would result if the operator tried to push a load too fast. Thus it was impossible to operate a large outboard motor anywhere near its maximum power rating, unless the boat was simply cruising from one place to another.

A second disadvantage of the outboard motor design was that the motors, intended for recreational use, failed frequently under the strenuous working conditions imposed on them by the boom-boat operators. Typically, the motor was worn out and in need of replacement after about three month's usage. Needless to say, users did not like the cost and inconvenience of repairing and replacing these motors.

For these two reasons -- cavitation and poor durability -- the outboard motor design was never really accepted by the industry.

In early 1966, a manufacturer in Vancouver was considering the boom-boat manoeuverability problem and had come up with two innovative design ideas. The first consisted of using a rotatable propeller housing, much in the manner of an outboard motor housing, but driving the propeller with a hydraulic motor contained inside the housing. The idea is shown in Figure 2. A conventional marine Diesel engine, mounted in the boom-boat hull, would drive a hydraulic pump, which would circulate hydraulic fluid to and from the motor through some sort of swivel coupling. As with the outboard motor design, the boom-boat would be steered by having the operator rotate the housing about the vertical axis, thus changing the direction of thrust.

QUESTION 3: Can you find anything wrong with this design?

The boom-boat manufacturer rejected the hydraulic motor idea because he realized it would be difficult to get the high pressure (in the order of 1500 psi) hydraulic fluid from a pump, fixed with respect to the boat's hull, to a motor which had to pivot freely through 360°. Other than mounting the entire hydraulic system (motor, pump, fluid reservoir, filters, and controls) inside the housing -- a seemingly impossible task in view of the sizes involved -- it appeared that two high-pressure swivel joints would be required in the hydraulic circuit. The manufacturer thought that these swivel joints would be difficult to design, expensive to manufacture, and very likely to leak. Furthermore, it was felt that maintenance of

a hydraulic drive system would be a problem. Not only did such machinery have to be serviced in special clean surroundings, but expensive precision spare parts needed to be kept on hand. In general, such requirements could not be met in the logging industry due to the remoteness of the locations in which the boom-boats usually operated. In addition, most logging company mechanics could not be expected to adequately service hydraulic machinery.

Thus, the boom-boat manufacturer directed his attention to another approach. This approach also used a diesel engine mounted in the hull, but brought power to the propeller through two sets of bevel gears, as shown in Figure 3. The propeller and vertical drive shaft were contained in a housing which could be rotated about the vertical axis by the operator, thus changing the direction of thrust and steering the boat.

QUESTION 4: Can you find anything wrong with this design?

The manufacturer thought this bevel gear drive idea looked good and decided to build a prototype. Six months later, after an expenditure of approximately $5,000, BEVEL 1 was launched before a crowd of excited plant employees. Everyone knew that if this design was successful, the plant would soon be working overtime filling orders, and paychecks would swell accordingly.

Unfortunately, after a few trial runs, it became apparent that something was very wrong with the design. First of all, the operator had to hold the steering wheel firmly in his hands to prevent it and the propeller housing from rotating. If he let go, the wheel and housing would rapidly rotate about their vertical axes and the boat would go nowhere. If he held the wheel firmly, with the propeller thrusting aft, the boat would swing in a gradual curve to the left. To offset this, the operator would have to steer about 20° to the right, an obvious waste of engine power. As can be imagined, it was much easier to steer to the left than to the right. In fact, as BEVEL 1 was put through its paces in the normal work environment, it was noticed that operators often turned 270° in the easy direction rather than 90° in the difficult direction. All operators complained of fatigue from constantly fighting the steering wheel torque.

No engineers had been involved in the project to this point.

QEUSTION 5: Can you explain BEVEL 1's behavior? Hint: The drive system contains an unbalanced torque, perhaps best discovered by drawing free-body diagrams of the various drive components.

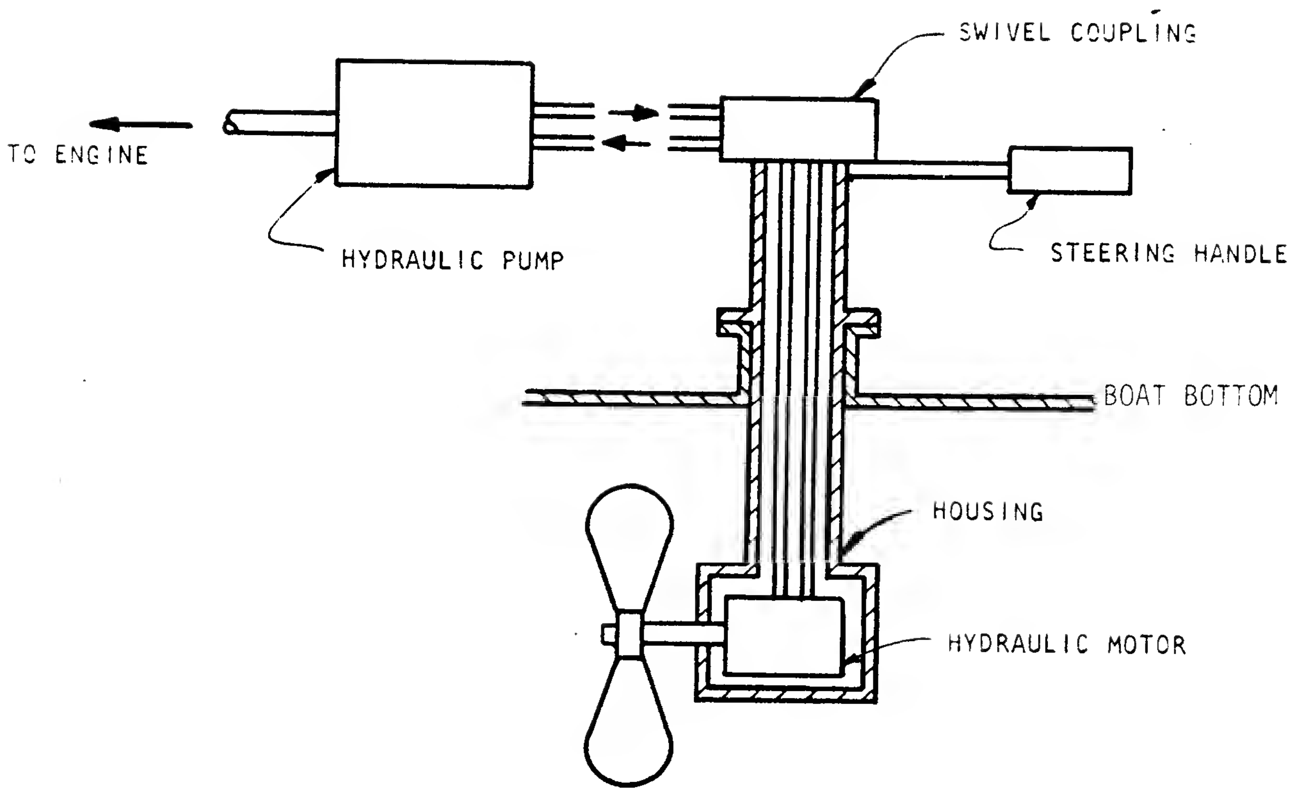

Fig. 2: Hydraulic Drive Idea

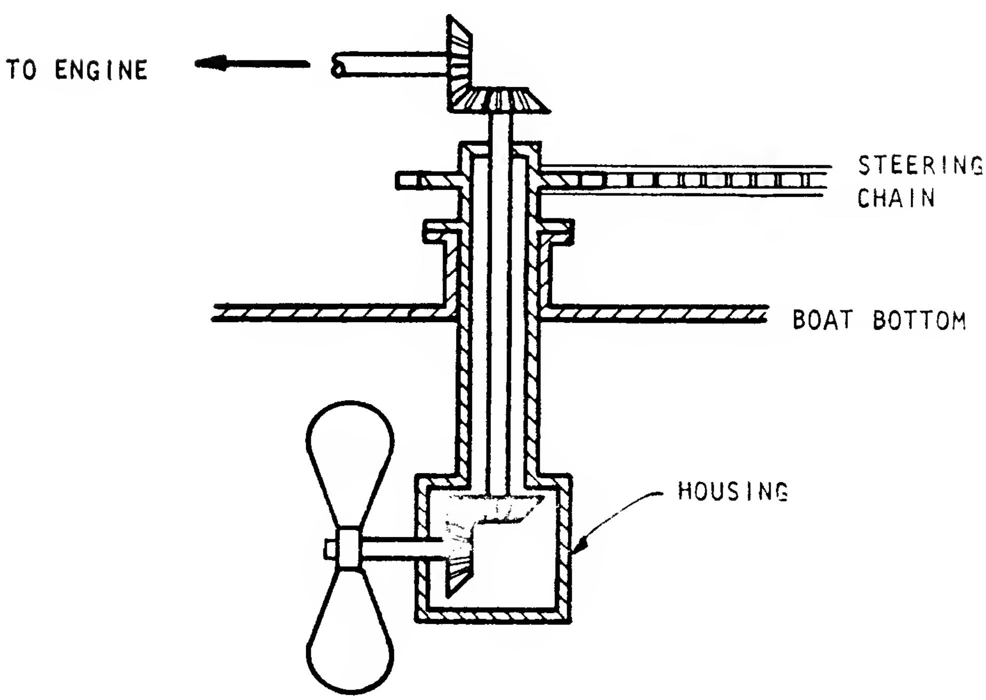

Fig. 3: Bevel Gear Drive Idea

The manufacturer realized that some sort of torque unbalance existed, but was unable to pin it down. Convinced that there was merit in the basic idea, he decided to solicit professional engineering help from the British Columbia Research Council. The B. C. Research Council, located in Vancouver offers research, development, and marketing expertise to B. C.'s government and industry. Although it is partially supported by the provincial government, the bulk of the Council's income is derived from contracts made with its various clients.

QUESTION 6: Imagine you are the manufacturer and you are meeting with the Research Council's Engineering Director. Your company has taken the boom-boat drive development as far as it can, and is about to draw up a contract asking the Council to develop a suitable drive system. Can you draw up a set of specifications for a "suitable drive system"?

The problem as presented to the Council was to design a "workable drive system" for the boom-boat application. To be "workable", the system had to:

1. Be capable of transmitting up to 200 horsepower, with the propeller turning at 1000 rpm;

2. Permit quick, easy change of thrust direction around a full 360°. Ideally, the operator should be able to change the thrust direction through 360° in less than one second;

3. Have all torques and forces balanced, such that the torque transmitted to the propeller in no way affected steering;

4. Be simple enough that any truck mechanic on the coast could service it. (The company did not wish its clients to have to train special maintenance personnel.)

Although not specifically stated, it was understood by both parties that low cost and high reliability were extremely important.

Having specified the work he wanted done, the manufacturer now wanted to know how much it was going to cost. At that point, Ray Sanders, a 45 year old mechanical engineer, was brought in on the discussion to see if he could estimate a cost. Ray immediately realized that in contrast to something like a construction project, where the final form of the product is known, and standard cost estimating techniques can be applied, the solution to the drive problem was not known. Thus, a conventional

engineering cost estimate could not be made -- at least not right away.

QUESTION 7: If you were in Ray's position, how would you recommend the Council should enter into a working arrangement with the manufacturer?

Ray considered the possibility of proposing that the work be done on a cost-plus-overhead basis. The "cost" aspect of such an arrangement would include all costs directly attributable to the project; e.g., engineering, drafting, and machining times at fixed hourly rates, materials costs, etc. The "overhead" charge would be calculated as a fixed percentage of the direct project cost, and would cover indirect expenses such as secretarial and administrative salaries, building mortgage, heat and electricity, etc., plus a certain amount of profit. However, from his past experience, Ray knew that the manufacturer would be reluctant to enter into such an agreement. With his limited development budget, the manufacturer would need to have the cost well defined. Ray asked, therefore, that he be given a few days to think over the problem, to see if he could think of a solution and estimate the cost of developing it. The manufacturer agreed to this, but pointed out that it would be very desirable if the idea could be developed in time for demonstration at a logging industry convention which was to take place in ten weeks' time.

Ray's first step was to concentrate on the manufacturer's bevel gear drive, in an attempt to see if the torque unbalance could readily be eliminated. Through his past experience he knew intuitively why the unbalance existed. However, for those not gifted with such intuition, a free body analysis is now presented.

The forces acting on the propeller shaft are shown in the free body diagram, Figure 4. To rotate the propeller in the water, a torque, T, has to be applied to the propeller shaft. This torque is transmitted to the shaft by the action of the driving bevel gear (not shown) on the driven gear, G_1. The transmission can be represented as a force, F_1, acting on the upper surface of G_1 a distance R from the shaft centerline, where $F_1 \times R = T$.

For the propeller shaft to be in static equilibrium, the housing bearing has to exert a force, F_2 and a couple, M_1, on the shaft. Equilibrium requires that F_2 be equal in magnitude but opposite in direction from F_1, and that $M_1 = F_1 \times D$, where D is the distance between the points of application of F_1 and F_2.

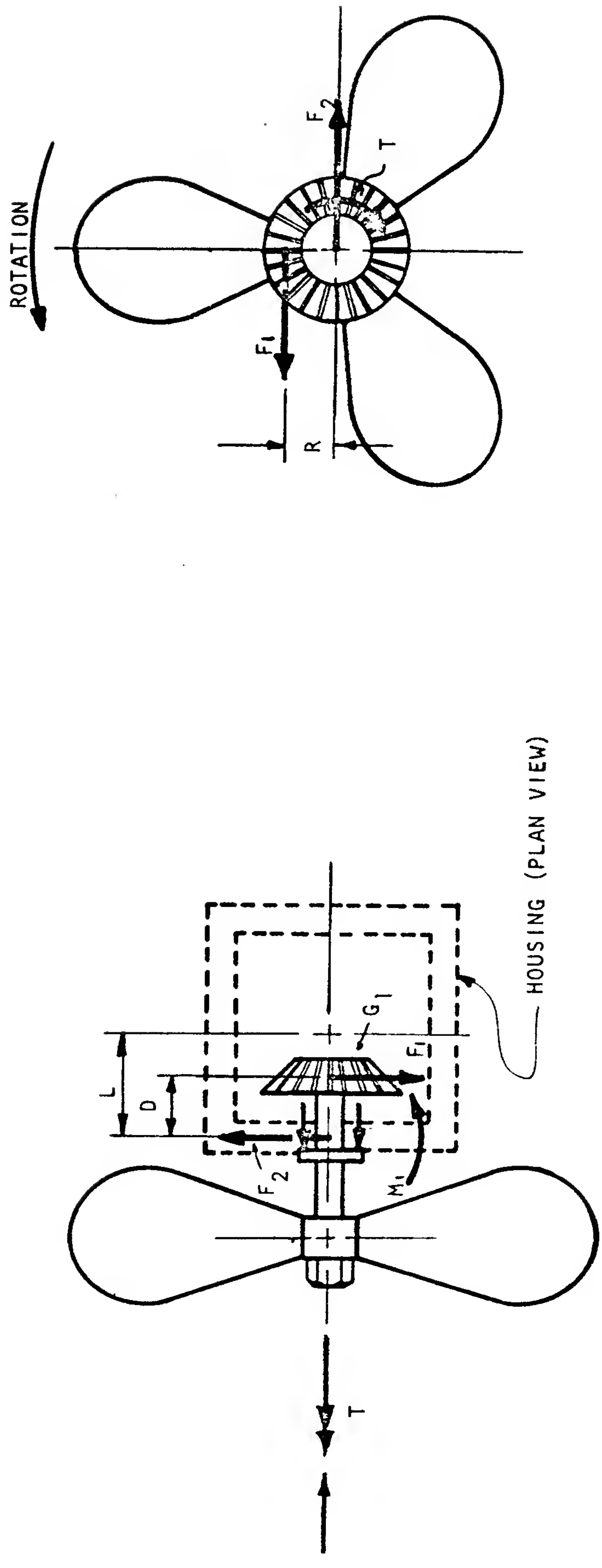

Fig. 4: Forces and Moments Acting on Propellor Shaft

Realizing that F_2 and M_1 act on the housing in senses opposite those shown in Figure 4, it can be seen that there are two moments of opposite sense acting about the housing's vertical axis. The net moment in the counterclockwise direction in Figure 4 is given by:

$$\begin{aligned} \Sigma M &= (F_2 \times L) - M_1 \\ &= (F_2 \times L) - (F_1 \times D) \\ &= F_1\ (L - D). \end{aligned} \qquad \ldots\ldots\ldots \quad (1)$$

Inasmuch as the distance (L-D) was not equal to zero in the prototype, an unbalanced torque acted on the housing and tended to rotate the housing about its vertical axis. When the operator held the steering wheel firmly, the unbalanced torque was transmitted to the boat itself, and this is what caused the boat to steer off course.

Notice that Equation 1 could have been derived more easily by simply considering F_1 as an unbalanced external force acting a distance (L - D) from the housing centerline.

With the torque unbalance problem explained by Equation 1, Ray next asked himself how the unbalance might readily be eliminated.

QUESTION 7: Can you suggest how the torque unbalance problem might be remedied?

One thought immediately came to Ray's mind: eliminate the unbalance by making F_1 pass through the housing's vertical axis; i.e., by making the distance (L - D) in Figure 4 equal to zero. Another possibility was to extend the propeller shaft so it was supported at both ends by the housing. Adding the additional support would cause an additional force to act on the housing, hopefully cancelling out the torque unbalance caused by F_1.

QUESTION 8: Discuss the practicality of solving the problem by either of these two approaches.

Unfortunately, Ray could think of no practical way of reducing (L - D) to zero. In order to transmit power through the rotatable housing, the centerline of the vertical drive shaft had to coincide with the centerline of the housing. Thus, there appeared to be no way of offsetting the drive shaft from the housing centerline. Furthermore, Ray could think of no mechanical device, equivalent in function to the bevel gear

pair, which would transmit power at right angles without using an offset equivalent to distance (L - D).

The idea of supporting the shaft at both ends is investigated by means of a free-body diagram of the shaft, Figure 5. This is essentially Figure 4 with an additional support force, F_3, added a distance, L, from the housing centerline.

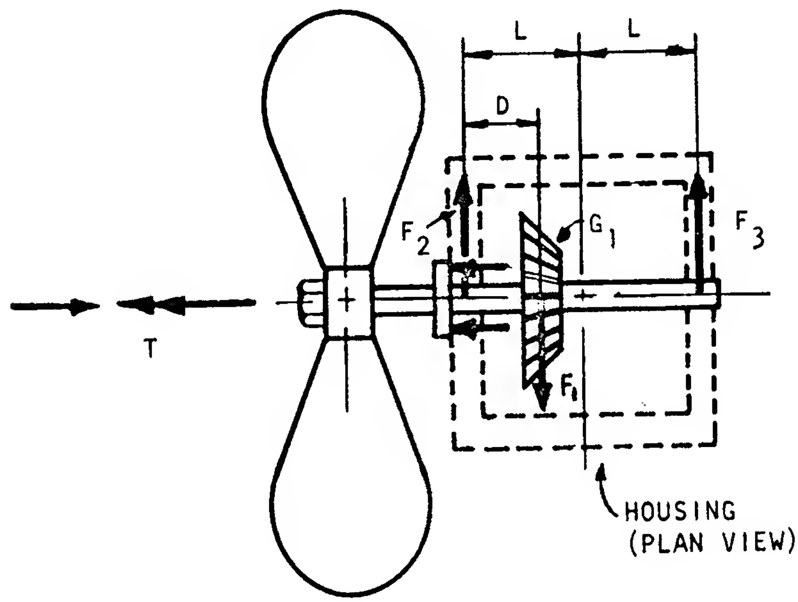

Fig. 5: Forces Acting on Doubly-Supported Shaft

The moment tending to rotate the housing counterclockwise is given by:

$$\Sigma M = F_2(L) - F_3(L) \qquad \text{. . . . .} \quad (2)$$

Taking moments about the right and left hand supports, gives:

$$F_2 = \frac{F_1(2L-D)}{2L} \quad \text{and } F_3 = \frac{F_1 D}{2L}$$

Substituting these values for F_2 and F_3 in (2) gives:

$$\Sigma m = \left| \frac{2L-D}{2} - \frac{D}{2} \right| F_1$$

$$= (L-D)F_1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Equation 3 shows that the additional support does nothing as far as eliminating the torque unbalance is concerned. Note again that Equation 3 could have been derived more easily by simply considering F_1 as an external force acting on the housing-shaft system.

The easy solution Ray had hoped for did not appear to be at hand. He turned the problem over in his mind for awhile, but, seeing no answer, decided to go on with some other work. This was a strategy Ray had often used in the past. When a solution was not immediately at hand, he would concentrate on the problem for awhile, then purposely put it out of his conscious mind. He, and many others, believe that one's subconscious mind works on the problem during the "rest period" and that in many respects it can work best undisturbed but for a periodic concentration on the problem. From his past experience Ray knew that in all likelihood this procedure would provide some insight into the problem.

Sure enough, the next day the thought struck him that the housing, and therefore the boat, acted in a manner similar to the base of an electric motor. He thought of a motor suspended along its shaft axis by a wire, and realized that it could do no work because it had no base to supply the torque necessary to counterbalance the load torque. If the vertical drive shaft exerted a torque on the propeller shaft, the boat had to exert a torque on the vertical drive shaft. He wondered if there was any other way of arranging things such that the boat no longer had to act in the manner of an electric motor base. Then it hit him: WHAT IF THE DRIVE SHAFT TORQUE WAS DIVIDED IN TWO AND SOMEHOW EACH HALF ACTED IN THE OPPOSITE DIRECTION? This would lead to a balance, with one torque opposing the other, and no net torque would be transmitted to the housing and boat.

Ray liked this idea. He felt he was on the right track, but the mechanical implementation of the idea was not immediately apparent. He went back to his other work, pausing periodically to ponder the problem.

QUESTION 9: Can you think of a mechanism which will divide one torque into two opposing torques, and then bring them together again to drive the propeller shaft?

Two days later, he sat down to collect his thoughts. His pondering had led him to believe that splitting the torque in two meant that two vertical drive shafts would be required. The easiest way of implementing this was to have the two shafts concentric. Furthermore, the original problem was caused by a force on the propeller shaft bevel gear causing an unbalanced moment about the vertical shaft centerline. He had considered the possibility of reducing the moment arm to zero without success. Just then he realized that the moment could also be cancelled by setting up an equal, but opposite, force on the other side of the bevel gear. A second drive gear, rotating in the opposite direction from the original drive gear, would provide such a force.

His mind was racing at this point, and suddenly this part of the solution was clear to him. As shown in Figure 6, power could be brought down to the propeller area through two concentric, but oppositely rotating, shafts. A bevel gear on the end of each shaft would transmit the power to the propeller shaft via the propeller shaft bevel gear. Since the two driving gears were rotating at the same speed, but in opposite directions, the forces F_1 and F_4 set up on the driven gear would be equal and opposite, and the resulting moments about the housing centerline would cancel.

So far, so good, thought Ray. The next problem was to think of a way of transmitting power from the horizontal engine shaft to the two oppositely-rotating, concentric, vertical drive shafts. The power had to be transmitted in such a way that the entire assembly could be rotated through 360° for steering.

QUESTION 10: How would you do this?

It appeared obvious to Ray that a planetary drive would be a convenient means of getting the two concentric shafts rotating in opposite directions. Figure 7 shows the concept. With this arrangement, the ring gear and outer shaft would be driven counterclockwise off the engine shaft by G_4. By preventing the

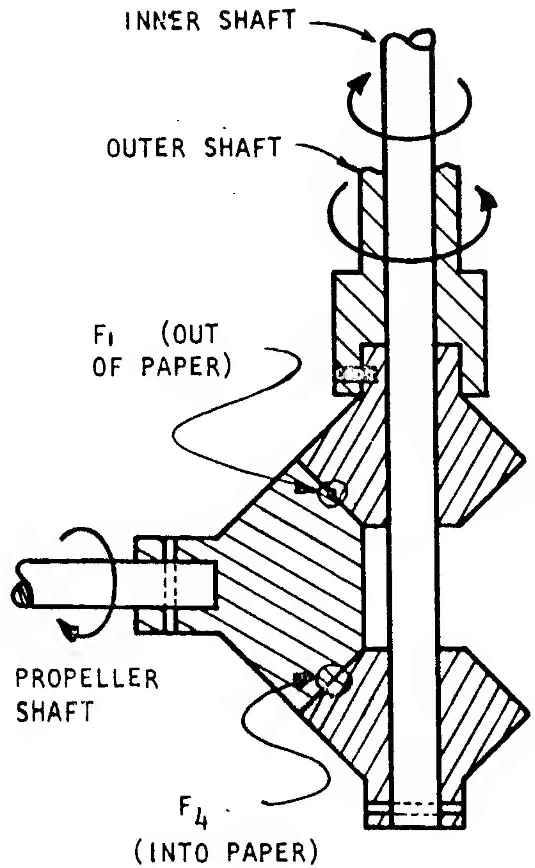

Fig. 6: Use of a Second Drive Gear to Set Up a Force, F_4, Opposing F_1

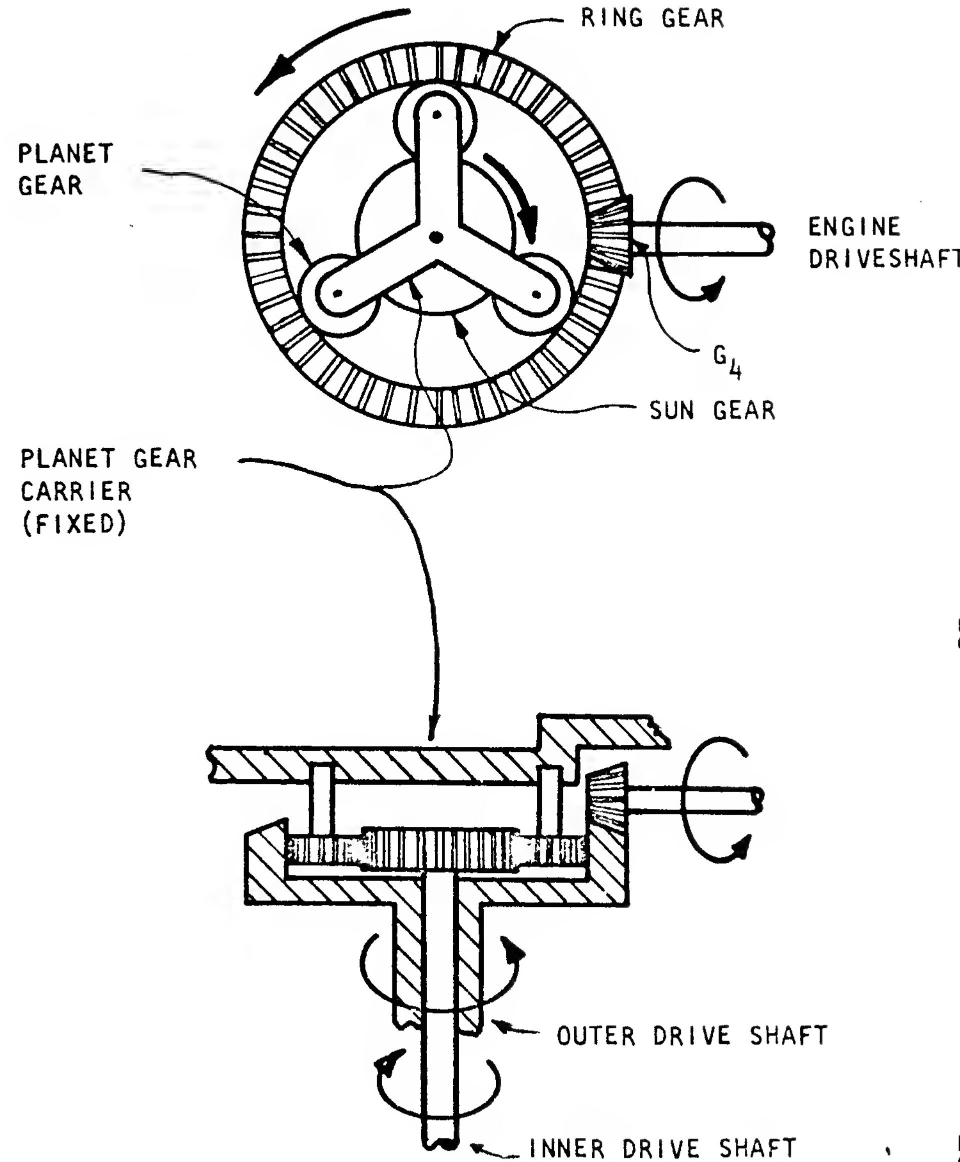

Fig. 7: Planetary Drive Concept

planet gear carrier from rotating, the sun gear and inner shaft would then be driven clockwise as desired.

QUESTION 11: What is wrong with this concept? HINT: Have a look at the angular velocities of the two vertical shafts.

It may be shown that with the planet gear carrier fixed, the inner shaft rotates N_r/N_s times as fast as the outer shaft, where N_r and N_s are the number of teeth on the ring gear and sun gear respectively. The problem with the concept shown is that N_r must necessarily be greater than N_s, hence the two shafts must rotate at different speeds. Typically, N_r might be about twice N_s, which would mean that the inner shaft would rotate about twice as fast as the outer shaft.

After pondering this for some time, Ray realized that the inner and outer shafts could not be connected directly by a planetary drive. If the ring gear being driven by the engine shaft were rotating at ω RPM, he felt the answer lay in using a planetary mechanism to drive the outer shaft at 2ω RPM, and then using a separate mechanism to drive the inner shaft in the opposite direction at 2ω RPM.

QUESTION 12: Can you sketch a suitable arrangement?

Ray was pondering this problem, looking for a solution, when it struck him that the propeller drive he had devised (Figure 6) looked something like an automobile differential. This thought reminded him of an earlier experience, when he had been playing with a small model of a differential in an attempt to understand how it worked. One of the features of the differential which had stuck in his mind was that if one output shaft were fixed, the other would rotate at twice the input velocity. This gave him the clue he was looking for, and it wasn't too long before he had sketched the solution shown in Figure 8.

In Figure 8, the engine drives the ring gear at ω RPM clockwise (in plan view). By proper choice of planet, ring and sun gear sizes, the planetary mechanism drives the outer shaft at 2ω RPM counterclockwise. The differential housing rotates at ω RPM clockwise with the engine-driven ring gear. Because the differential's top shaft, S_1, is fixed, the bottom shaft, S_2, is driven at 2ω RPM clockwise, as desired.

QUESTION 13: Verify the action of the differential with its top shaft fixed.

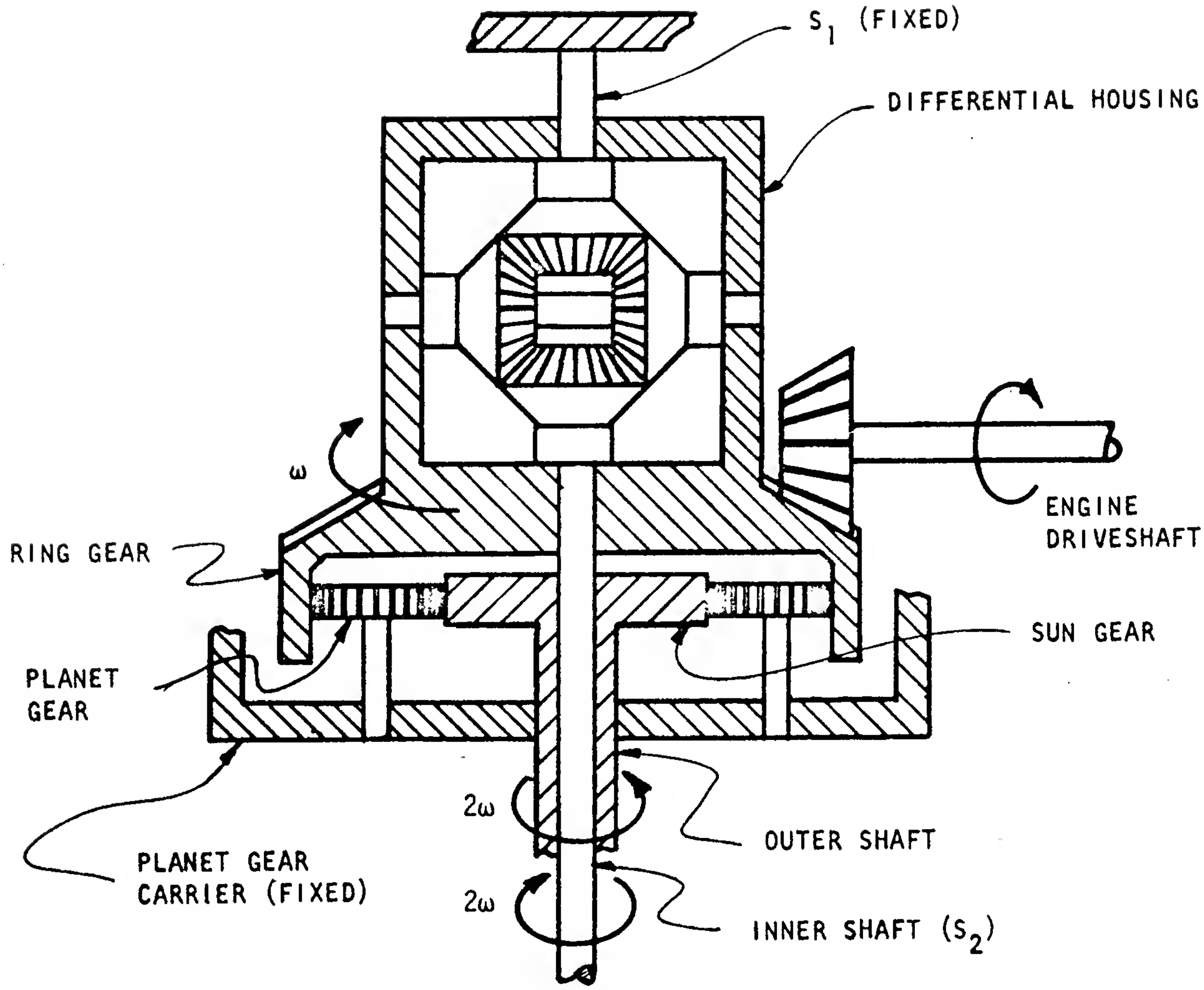

Fig. 8: Combination of Planetary and Differential Drives

Ray was pleased with the conceptual solution so far, and directed his attention to the last major aspect of the problem - steering. In attempting to devise a way of rotating the drive assembly, he recalled his earlier thought that the gears driving the propeller shaft in effect comprised a differential mechanism. By directing his thoughts to the action of a differential, he remembered that if the inner and outer shafts (Figure 6) were turned simultaneously in the same direction the entire housing would rotate in that direction. All that he needed, then, was some means of rotating the two shafts simultaneously in the same direction.

Still thinking about differentials, he next remembered that turning shaft S_1 in the top differential (Figure 8) caused an opposite rotation in the shaft S_2. He also realized that the outer shaft could be turned by rotating the planet gear carrier around the outer shaft. By performing these actions simultaneously, the inner and outer shafts could be rotated in the same direction, thus rotating the propeller housing and steering the boat. Notice that the actions required for steering can be performed independent of (i.e., superimposed on top of) the normal drive shaft rotations.

Having established this, the solution was relatively easy: simply gear the top differential shaft and the planetary gear frame to a common shaft. The final solution is shown in the patent drawing, Figure 9*. Turning the common shaft (68) by means of a chain (71) connected to the steering wheel causes the differential shaft (21) and the planet gear carrier (75) to rotate in the same direction. This action causes the inner and outer shafts to rotate together, and the differential at the bottom converts this into a rotation of the propeller housing. The actions of the top differential (numbers in the range 17-30), the planetary mechanism (numbers 36, 42, 44, 45, and 75), and the bottom differential (53-66) should be apparent from previous explanations. Note that an idler gear, 56, has been added to the original propeller drive concept shown in Figure 6. This idler was added to increase the rigidity of the drive system.

The design concept was now complete. Feeling its feasibility would best be demonstrated by a model, Ray next directed his attention to estimating the cost of developing the model. To do this, he had to do some detailed design work -- specifying the various gear ratios to give the necessary speed or torque ratios, choosing the gears from stock parts, then tying the whole thing together in a suitable framework. To keep costs down, he gave little thought to weight, proper seals and bearings, and appearance -- matters which would be important in the finished product but not in the demonstration model. Having done this, he was then able to estimate the cost of the various components, machine shop time, and testing time. Including the cost of the time he had already put into the project, his estimate for the development of a model came to $1,000.

Ray presented his proposal to the manufacturer, who indicated he was satisfied -- providing it worked. He agreed to spend up to $1,000 to test the feasibility of the idea.

---

*Note that the patent drawing is out of chronological order here. In actuality, it did not originate until some time later.

July 16, 1968 R. J. SANDERS 3,392,603

DRIVE AND STEERING UNITS

Filed Nov. 14, 1966 2 Sheets-Sheet 1

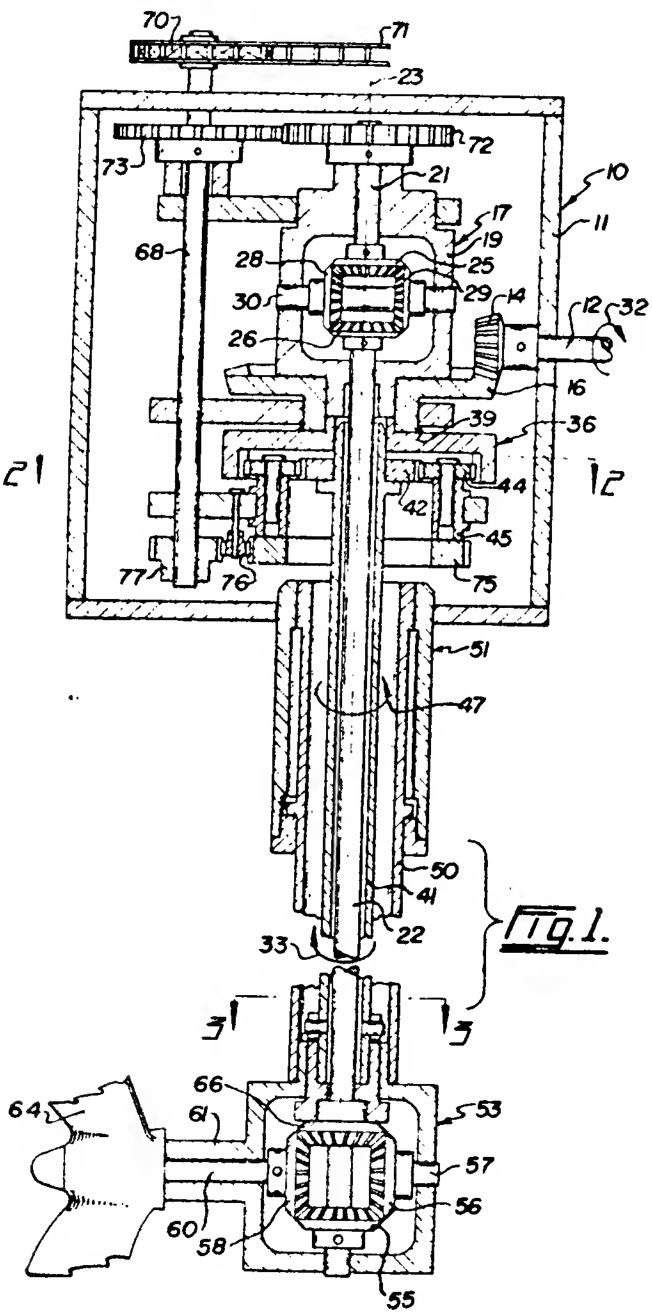

Fig. 9: Patent Drawing Showing the Entire Drive and Steering Concept

INVENTOR
RAYMOND J. SANDERS
BY
Fetherstonhaugh & Co.
ATTORNEYS

QUESTION 14: Who has the rightful claim to any patent rights which might arise out of the work?

The manufacturer had come to the Council with a problem only - no solution. Furthermore, the manufacturer hadn't paid the Council for the time Ray spent developing the idea, nor had any legal agreement been made. Legally, therefore, the Council could probably have claimed the patent rights. Ethically, however, it would have been a severe breach of trust for the Council to claim the rights, and there was no question of its doing so. In the contract which was drawn up, it was agreed that any patents arising from the work would be the property of the client should he decide to accept them. Should he not decide to accept them within six months, the Council could claim the rights it it wished.

The model was completed one month later by the Research Council staff. Once completed, it was connected to a variable speed electric motor, and the propeller housing was immersed in an oil bath. (Oil was used instead of water to prevent rusting of the mild steel parts used in the model.) A Prony brake attached to the steering wheel indicated no unbalanced torque was developed in the system as the motor was run over a wide range of speeds. With the brake removed and the motor running, the housing could be rotated easily by turning the steering shaft. It was concluded that the idea was sound and that construction of a final product could begin.

At this point, the manufacturer had to decide if the idea was worth patenting.

QUESTION 15: Can you think of some disadvantages of filing for a patent?

The manufacturer knew that obtaining a patent was going to cost somewhere between $1,000 and $2,000 with filing fees, attorney fees, and the fees which would have to be paid to the Council for documenting Ray's ideas in detail. Furthermore, he knew that any competitor could very quickly become familiar with all the work which had been done, simply by getting a copy of the patent. Thus, any competitor would be on an equal footing as far as making improvements (not covered by the patent) was concerned. Nonetheless, it was felt that the competitive edge offered by the patent would outweigh these disadvantages, and an attorney was hired to initiate search and application procedures.

At this point, Ray reviewed his design to see if there was any way to simplify it. He knew this was a very important step as far as his client was concerned, since once the patent was issued, or the device was put on the market, every boom-boat manufacturer in the world would be trying to improve on his design in an attempt to procure a patent on an improved design. He somehow felt that two vertical shafts transmitting power to the propeller were an unnecessary duplication, but could think of no simplification.

QUESTION 16: Can you think of a better way?

Three days later, it suddenly hit him that a torque was required to hold the differential shaft 21 (Figure 9) fixed. Furthermore, the housing in the manufacturer's original design (Figure 3) rotated because there was nothing to resist the torque generated by the unbalanced force on the propeller shaft gear. Was there any way the differential shaft holding torque could be used to directly counter-balance the housing torque?

Having had this revelation, it did not take him long to sketch the idea shown in Figure 10. (Figure 10, copied from the final patent, is out of chronological order here.) The lower half of this unit is a simple right-angled drive, as in the manufacturer's original design. The vertical drive shaft (22) is driven by the differential (17) with its upper output shaft (21) fixed to gear 73. Gears 73, 72, 77, 76, and 75b form a link connecting shaft 21 to the rotatable housing (50). The torque required to prevent shaft 21 from rotating is transmitted directly to the housing, thus preventing it from rotating. Notice that idler gear 76 is necessary to insure that the torques generated by the shaft and the housing oppose each other. Steering is simply a matter of turning shaft 68.

Ray was impressed with the simplicity of his new design. When asked why he hadn't thought of it earlier, his reply was that a first design is always complicated. At this stage, separate components are generally specified for each separate function. The step he took was simply one of reducing the number of components by making some components perform multiple functions.

The manufacturer also liked the simplicity of the new idea, but was somewhat concerned about the prospect of proceeding without proof of performance. Ray assured him it would work, however, so it was decided to proceed with it. A second contract was entered into at this point, in which the manufacturer agreed to pay the Council $10,000 to produce a complete set of production drawings and specifications for a commercial unit. The work was

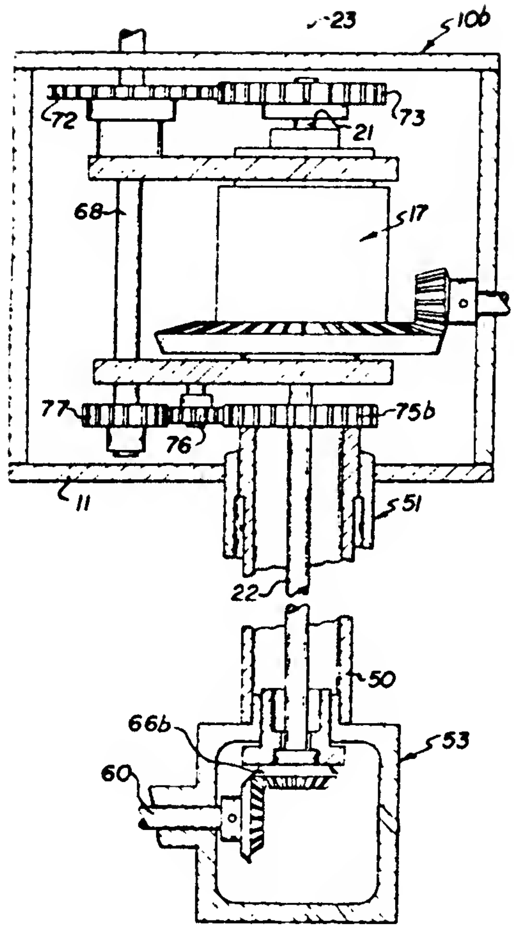

Fig. 10: Simplified Drive and Steering System

to include a stress analysis of each component and a search for readily available stock components. Any work done by the Council in preparing the patent application was to be paid for on an hourly basis in addition to the $10,000.

The desire to demonstrate a working prototype in the forthcoming logging industry convention made the next six weeks a flurry of activity. Drawings were passed on to the manufacturer's fabrication shop as soon as they were made, and machinists worked overtime to complete the unit. The unit was finished the night before the convention, and much to everyone's delight and amazement (in view of the rush), it worked beautifully.

U. S. Patent No. 3,392,603, entitled Drive and Steering Units, was issued on July 16, 1968 -- approximately 2-1/2 years after the conception of the idea. It covered the two configurations of Ray's idea, as shown in Figures 9 and 10.

The boom-boat drive system developed by Ray Sanders represents the state of the art. Boom-boat operators are pleased with the drive's high reliability, ease of operation, and ease of maintenance. Competitive units all use some sort of hydraulic power steering system to overcome the inherent torque unbalance in the drive, and the result is a heavier, less efficient, and slower-responding drive unit. The manufacturer has developed a very successful business out of the idea, and is presently filling orders from as far away as New Zealand.

INSTRUCTOR'S NOTE

In writing this case I had in mind allowing the engineering student to follow through the same thought processes as went on in Ray Sander's mind as he created his design. To this end, I have presented the design process step by step, with each step ending in a question. My hope is that this will allow the instructor to describe the design process to a certain point, ending the description with a question. The students can then ponder the question and respond to it, in effect completing the next step of the process themselves. The instructor can then describe how Ray took the step (feedback), a discussion can follow, the next question can be posed, and so on. If used this way I feel the case will be much more than the telling of a story. It should force students to think in the manner of a designer, and learning should result.